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Further Noise Measurements in a Slotted Cryogenic Wind Tunnel

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FURTHER NOISE MEASUREMENTS IN A SLOTTED CRYOGENIC WIND TUNNEL

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SUMMARY

This Memorandum describes some noise measurements in a cryogenic wind tunnel with slotted walls at subsonic and transonic speeds. Pressure fluctuations were measured at three positions on the sidewall of the working section, the downstream end of the plenum chamber and near the inlet and outlet of the first diffuser.

Analysis of the measurements suggests that the diffuser noise field can be represented by the superposition of monopole, dipole and quadrupole sources. The existence of these sources suggests that the diffuser flow may be separated for a significant portion of its length, either because of poor entry conditions or the presence of the model support strut. As expected, a small model at a small angle of incidence generally has a small effect on the noise measurements in the working section. Recommendations are made for further research.

LIST OF CONTENTS

1 INTRODUCTION

An earlier Report[1] describes a comprehensive series of noise measurements in a cryogenic wind tunnel - the Pilot Wind Tunnel (PETW) for the European Transonic Wind Tunnel (ETW). During the analysis of those measurements two specific questions arose which were addressed by some brief complementary measurements reported here. These questions arose which were addressed by some brief complementary measurements reported here. These questions are:

(i) how does the diffuser noise relate to the working section noise and what are the main sources of diffuser noise?

(ii) what is the influence of a lifting model on the tunnel noise?

With regard to the first question, it is found that the diffuser noise has a strong influence on the working section noise and that it has characteristics of monopole, dipole and quadrupole sources. With regard to the second question, it is found, as expected, that a lifting model at a small angle of incidence has a comparatively small influence on the noise in the working section.

2 EXPERIMENTAL DETAILS

A comprehensive description of the experimental details is available in Ref 1 and for brevity this is not repeated here. It suffices to say that the noise measurements are presented as total broad band rms levels, $\tilde{p}/q$, or spectral levels, $\sqrt{nF(n)}$, versus the frequency parameter, n , or the frequency, f , as recommended by Owen[2]. According to Owen's notation

$$\frac{\overline{p^2}}{q^2} = \int_{n=0}^{n=\infty} F(n)\, dn \quad , \qquad (1)$$

where $\overline{p^2}$ = power of pressure fluctuations,

n = fw/U - frequency parameter,

$F(n)$ = contribution to p^2/q^2 in a frequency parameter band Δn ,

U = free stream velocity in the working section,

q = $\frac{1}{2}\rho U^2$ = kinetic pressure

and w = width of working section.

The measurements in the first diffuser were made at the inlet (D1) and the outlet (D2) as shown in Fig 1a. A 'mock-up' second throat was formed by wedges on the strut and fairings on the sidewall. For these measurements the centre line cone of Ref 1 was replaced by a small, sting supported pilot model, set at an incidence of -5° (Fig 1b).

Ae 2201

All measurements were made with the slots in the top and bottom slotted liners open and the flaps at the end of the plenum chamber open. The tunnel total pressure was 1 bar and the total temperatures 120 and 240 K. The Mach number range extended from about $M = 0.3$ to choking with and without the second throat.

3 RESULTS

The diffuser noise measurements are considered in section 3.1. The small influence of the model is discussed in section 3.2.

3.1 Diffuser noise

3.1.1 Tunnel without second throat

Fig 2 shows the rms noise at $T_t = 120$ K and 240 K. For the diffuser inlet (Fig 2a) the noise increases monotonically with the free stream Mach number above about $M = 0.4$ and can be represented by the relation

$$\frac{\bar{p}}{q}\ (\%) \quad = \quad 0.84 + 1.24\,M^2 \ . \tag{2}$$

For the diffuser outlet (Fig 2b) the measurements can be represented by the relation:

$$\frac{\bar{p}}{q}\ (\%) \quad = \quad 1.54 + 0.73\,M^2 \ . \tag{3}$$

Equations (2) and (3) imply that there are no scale effects on the diffuser flow because the measurements at both total temperatures are identical.

The spectra of the rms noise measurements give additional information about the three different types of noise source. A logarithmic scale is used for the frequency parameter. For the diffuser inlet, the spectra (Fig 3) are generally flat at about $\sqrt{nF(n)} = 0.006$ up to a frequency parameter n varying from about 7×10^{-1} to 3×10^{-1}, then increase rapidly to a much higher level. There are two almost identical peaks at each Mach number; for instance for $M = 0.7$ these are at $n = 5 \times 10^{-1}$ and $n = 4$. The level of both these peaks above $\sqrt{nF(n)} = 0.006$ increases roughly proportional to M^2 (Fig 4a). This part of the spectrum represents the second term of equation (2). The constant portion of the spectrum represents the first term in equation (2). This situation is illustrated in the idealised sketch of Fig 4b.

The crucial question must now be addressed as to whether these diffuser inlet noise measurements can be related to those in the working section of the datum tunnel? Fig 5 compares the diffuser inlet noise spectra for $T_t = 120$ K with those in the working section at $M = 0.8$ and choking. For high speeds, such

as M = 0.80 (Fig 5a) the first peak in the diffuser coincides with the 'plenum ramp' noted in the working section[1]. This coincidence suggests that disturbances from the plenum chamber could convect downstream and drive the diffuser separations near the inlet and/or the flow about the strut. This then would account for the idealised spectra (Fig 4b) of the noisy diffuser. This hypothesis would be consistent with the radically different measurements at choking. For choking conditions, there are still disturbances in the downstream end of the plenum chamber[1] which could convect downstream into the diffuser inlet, which consequently remains noisy (Fig 5b). However, the working section noise (also shown in Fig 5b) remains low because the diffuser noise can no longer propagate upstream.

3.1.2 Tunnel with second throat

Fig 6 shows the rms noise for the tunnel with the second throat at T_t = 120 K and 240 K. Choking occurs at M = 0.73 corresponding with $M^2 = 0.53$. For the diffuser inlet (Fig 6a) the noise increases monotonically with Mach number from about M = 0.4 to M = 0.7, and can be represented by the relation

$$\frac{\bar{p}}{q}\ (\%) \quad = \quad 1.00 + 1.60M^2 \ . \tag{4}$$

For the diffuser outlet (Fig 6b) the measurements can be represented by the relation

$$\frac{\bar{p}}{q}\ (\%) \quad = \quad 1.70 + 1.60M^2 \ . \tag{5}$$

Equations (4) and (5) confirm the previous findings[1] that there are no scale effects on the diffuser flow because the measurements at both total temperatures are identical.

Fig 6 shows another feature which is worth comment. On choking, the noise at the diffuser inlet suddenly increases. This increase can be attributed to the approach of the shock system downstream of the sonic throat. In contrast the noise at the diffuser outlet suddenly decreases, due to the general steadiness (particularly at low frequencies) enforced on the flow all around the tunnel circuit by the sonic throat. This reduction in the random noise could have an influence on the fan noise at discrete frequencies, as discussed previously in Appendix A of Ref 1.

Fig 7 shows some typical pressure fluctuations at the diffuser inlet. For M = 0.30 (Fig 7a) the spectra at T_t = 120 K and 240 K are almost the same apart

from the transducer resonance at about fw/U = 10 at the lower total temperature. For M = 0.60 (Fig 7b) the spectra at T_t = 120 K and 240 K are also almost the same, apart from a curious peak in the spectrum at the higher total temperature at a frequency parameter of fw/U = 0.25 . This peak is thought to be the noise due to a plenum chamber resonance excited by the model (*cf* section 3.2) and is used below (*cf* discussion of Fig 8) to illustrate the link between the diffuser inlet and the working section. For the choking Mach number (Fig 7c) two curves are given for nominally identical free stream conditions (M = 0.72, T_t = 120 K). For the continuous curve the tunnel is about to choke. For the dotted curve the tunnel pressure ratio is a little higher so that the tunnel is choked. The diffuser inlet noise is then increased over the range of frequency parameter from about fw/U = 0.02 to about 8. This frequency range may be identified with the development of shock induced separation downstream of the second throat when that chokes. In contrast Fig 7c also shows that on choking the low frequency noise at the inlet is reduced up to a frequency parameter of about fw/U = 0.008.

Evidence has been presented (in section 3.1.1 and elsewhere[1]) for a possible connection between the noise in the first diffuser and in the working section. The peak in the diffuser noise at a frequency parameter of 0.25 at T_t = 240 K in Fig 7b can be used to test this inference directly. Fig 8 compares the corresponding noise measurements at T_t = 120 K and 240 K for M = 0.6 in the working section, the plenum chamber and the re-entry region. All three curves have peaks at fw/U = 0.25 at the higher temperature, exactly as in the diffuser inlet measurements of Fig 7b. For the working section (Fig 8a) the increase in peak noise is about $\sqrt{nF(n)} = 0.013$ and is confined to a fairly narrow region. For the plenum chamber (Fig 8b) the increase in peak noise is higher, about $\sqrt{nF(n)} = 0.017$, but there is an additional increase at frequencies above and below the peak. For the re-entry region (Fig 8c) the increase in peak noise is smaller than in either the working section or the plenum chamber, only about $\sqrt{nF(n)} = 0.008$. These observations suggest that the source of the noise could be a resonance in the plenum chamber. However the peaks are manifest both in the re-entry region and the diffuser inlet. It can only be hoped that such resonance phenomena will not be excited in the plenum chamber of the full scale tunnel[1].

3.2 Influence of model on noise

A brief assessment of the influence of a model (*cf* Fig 1b) on the tunnel noise was made during the measurements of the diffuser noise.

3.2.1 Tunnel without second throat

Here direct comparisons with the original measurements[1] are possible only for the downstream plenum chamber (E) because the installations of all the sidewall transducers (G,H,J) and the re-entry transducer (I) were altered. Despite this caveat, comparisons of measurements from the sidewall and re-entry transducers should indicate any large differences due to the model.

Fig 9 shows the variation of the rms noise with Mach number for $T_t = 240$ K. For the sidewall, Fig 9a suggests that the model lowers the noise a little over the complete Mach number range. A direct comparison is impossible because the small change could be attributed to the change in the transducer installation but it could be genuine, because the noise is definitely lower (Fig 9b) at the downstream end of the plenum chamber where a direct comparison is possible. Fig 9c suggests that the model may increase the noise in the re-entry region.

The origin of these differences may be found by comparing the noise spectra with and without the model at the downstream end of the plenum chamber at a typical condition. The condition selected is close to the maximum in the working section noise (at $M = 0.8$) at $T_t = 240$ K. Fig 10 shows that the model greatly reduces the noise at the 'plenum hump' although it may not change the 'ramp' observed in the sidewall spectra significantly. [This is true also at all other Mach numbers and at both $T_t = 240$ K and 120 K.] This decrease in noise at the downstream end of the plenum chamber may be attributed to the local flow about the model influencing the flow about the supports at the downstream end of the plenum chamber. This indicates the rapid changes in the flow at this particular position, because this small model at an incidence of only -5° would create only a small perturbation at the tunnel wall. This inference is consistent with the measurements with the second throat.

3.2.2 Tunnel with second throat

For this tunnel configuration direct comparisons in the noise are possible for the sidewall and the re-entry region, as well as for the plenum chamber.

Comparison of the $\bar{p}/q$ values with and without the model (Fig 11) show that it has no large effect on the noise except for $M = 0.6$. The spectra (Fig 12) show that the exceptional increase in noise due to the presence of the model at $M = 0.6$ is associated with a resonance peak about 250 Hz, which is the frequency of the second longitudinal mode in the plenum chamber at $T_t = 240$ K. There is currently no explanation for this peak at $T_t = 240$ K: there is no corresponding peak at $T_t = 120$ K.

With the second throat a similar peak at M = 0.6 and T_t = 240 K was observed with the original cone model[1], but it was lower than with the model. This peak was absent also without the second throat.

4 DISCUSSION

In the Appendix it is suggested that the noise in the diffuser comes from a combination of monopole, dipole and quadrupole sources. If this interpretation is accepted there are important implications for the design of the full scale tunnel, the European Transonic Wind Tunnel (ETW).

That the noise measurements can be expressed in terms of monopole, dipole and quadrupole sources suggests that the shear stresses generating this noise are present over the full working range of the tunnel, *ie* that there may be always a separation in the first diffuser, probably with reattachment roughly half way down the diffuser. However, there is currently no evidence for this separation. It is recommended that flow visualisation in the diffuser should be attempted. Such flow visualisation might be made at ambient conditions (T_t = 280 K), and this would be sufficient because there is no evidence of serious scale effects or effects peculiar to the cryogenic mode of operation[1]. If separation does exist, it may be possible to suppress it by appropriate fairings or vortex generators. Past experience[3,4] suggest that these modifications would reduce the pressure losses in the tunnel circuit, as well as reducing the noise. In the original tunnel test rig for the ETW with a closed working section, flow visualisation tests have suggested that the diffuser flow was always attached. However, the tunnel test rig was not fully representative of the ETW. It included neither the slotted working section (which will degrade the diffuser re-entry flow) nor the model support strut (which would be likely to create local separations).

There is a close link between the diffuser inlet and the working section noise. This link suggests in retrospect that the diffuser inlet noise should have been measured in all the tests of Ref 1. It would have been particularly interesting to see how the diffuser inlet noise varied when:

(i) all 12 slots were sealed and the flaps were closed (Ref 1, section 4.4);

(ii) when eight slots were sealed and when four were open and the flaps were open (Ref 1, section 4.5);

(iii) when the support beams were faired with the slots and flaps open (unpublished measurements) and

(iv) when the plenum volume was reduced with slots and flaps open (Ref 1, section 4.7).

Such measurements might clarify the relationship thought to exist between the 'hump' in plenum chamber noise and the 'ramp' in the working section noise[1].

Although the model apparently has a small influence on the working section noise, it had a low aspect ratio wing and was set at only -5° incidence. [It had been intended to test the model at 30° incidence but this was precluded by the transducer wiring.] Accordingly, further comparative tests with the model at 0° and 30° incidence are recommended.

5 CONCLUSIONS AND RECOMMENDATIONS

This Memorandum suggests three conclusions and three recommendations for further research.

(1) The noise field in the diffuser of this cryogenic wind tunnel may be represented by the superposition of m nopole, dipole and quadrupole sources.

(2) For the particular diffuser tested, the noise measurements suggest that the flow may be separated over the full operational range (Mach number, total temperature - and by inference total pressure), with reattachment about half way down the diffuser.

(3) As expected, a low aspect ratio model in the working section set at a small angle of incidence has only a small effect on the tunnel noise, except locally at the rear of the plenum chamber, where the effect is large.

The following recommendations are made for further research:

(i) It is important to establish whether separations do exist in the PETW diffuser.

(ii) If significant diffuser separations are found, an attempt should be made to eliminate them by aerodynamic modifications. The corresponding reductions in noise and pressure losses should be evaluated also.

(iii) Comparative tests should be made with the model at $\alpha = 0^{\circ}$ and 30° to confirm it has only small effects on the tunnel noise and the pressure losses.

Appendix

SIMPLIFIED MODEL FOR DIFFUSER NOISE

A simplified model for the noise observed at the two measurement positions is suggested here and sketched in Fig 13a.

Idealisation of diffuser flow

The diffuser flow is characterised merely by the inlet velocity, U_d. This velocity is assumed constant throughout the diffuser. This somewhat unrealistic assumption is necessary to obtain a simple model for the diffuser noise field. It is apparently justified by the reasonable predictions it gives. Subject to this assumption,

$$U_d = kU \quad , \tag{A-1}$$

where k = constant appropriate to the diffuser inlet area and the working section area. If the density and temperature in the diffuser are the same as that in the working section,

$$M_d = kM \ . \tag{A-2}$$

It follows from the assumptions made above that the velocity of sound is the same in the working section and the diffuser.

Possible types of noise source

Lighthill attributed aerodynamic noise to three different types of source[5], namely monopole, dipole and quadrupole. We will show that all three types are present in this diffuser.

The monopole noise is due to mass flow fluctuations within a particular volume of the diffuser (say the wake of the quadrant). The dipole noise is due to the unsteady force distribution on the surface of the diffuser and the model support strut. The most likely origin of the dipole field is the oscillatory flow about the model support strut induced by the vertical supports in the plenum chamber at the end of the working section[1]. The quadrupole noise is due to the shear stresses within the flow and is likely to be concentrated in the wake of the support strut, particularly, if, as feared, the flow about this strut is separated.

Far field noise

It is now possible to formulate approximate expressions for the far field noise in the diffuser due to the three types of source. However the terms representing the directivity of radiation due to the convection of sound sources and

the effects of speed increases towards $M = 1$ must be neglected, These terms were discussed in Ref 5 and included in the semi-empirical theory for the noise in the working section[6].

For the monopole noise the relationship between the acoustic power and the diffuser velocity is:

$$\overline{p^2} \propto \rho^2 U_d^4 \left(\frac{\ell_1}{x}\right)^2 , \tag{A-3}$$

where ρ = free stream density,

ℓ_1 = characteristic length of mixing region,

a = velocity of sound

and x = distance from source to measurement point.

Hence if free stream conditions are used as a reference,

$$\frac{\overline{p^2}}{q^2} \propto \left(\frac{U_d}{U}\right)^4 \left(\frac{\ell_1}{x}\right)^2 , \tag{A-4}$$

For a dipole source the corresponding relation for the far field noise is

$$\overline{p^2} \propto \frac{\rho^2 U_d^6}{a^2} \left(\frac{\ell_2}{x}\right)^2 , \tag{A-5}$$

with a characteristic mixing length ℓ_2 . Hence we find

$$\frac{\overline{p^2}}{q^2} \propto \left(\frac{U_d}{U}\right)^4 M_d^2 \left(\frac{\ell_2}{x}\right)^2 . \tag{A-6}$$

For a quadrupole source the far field noise is

$$\overline{p^2} \propto \frac{\rho^2 U_d^8}{a^4} \left(\frac{\ell_3}{x}\right)^2 , \tag{A-7}$$

with a characteristic mixing length ℓ_3 . Hence we find

$$\frac{\overline{p^2}}{q^2} \propto \left(\frac{U_d}{U}\right)^4 (M_d)^4 \left(\frac{\ell_3}{x}\right)^2 . \tag{A-8}$$

If the source strengths in equations (A-4), (A-6) and (A-8) are respectively B_1, B_2 and B_3 the total power of the noise field is the summation of the separate powers, *ie*

$$\frac{\overline{p^2}}{q^2} = k^4\left[B_1\left(\frac{\ell_1}{x}\right)^2 + B_2(M_d)^2\left(\frac{\ell_2}{x}\right)^2 + B_3(M_d)^4\left(\frac{\ell_3}{x}\right)^2\right] . \tag{A-9}$$

Taking note of equation (A-2), equation (A-9) gives

$$\frac{\overline{p^2}}{q^2} = k^4\left[B_1\left(\frac{\ell_1}{x}\right)^2 + B_2k^2\left(\frac{\ell_2}{x}\right)^2 M^2 + B_3k^4\left(\frac{\ell_3}{x}\right)^3 M^4\right] . \tag{A-10}$$

The rms noise measurements in both positions without and with a second threat can be written as

$$\frac{\bar{p}}{q} = a_0 + a_1M^2 , \tag{A-11}$$

as may be seen from equations (2), (3), (4) and (5). Hence the mean square pressure is

$$\frac{\overline{p^2}}{q^2} = a_0^2 + 2a_0a_1M^2 + a_1^2M^4 . \tag{A-12}$$

Equating the coefficients of the various powers of M in equations (A-10) and (A-12), we find

$$k^2\sqrt{B_1}\left(\frac{\ell_1}{x}\right) = a_0 , \tag{A-13}$$

$$k^3\sqrt{B_2}\left(\frac{\ell_2}{x}\right) = \sqrt{2a_0a_1} , \tag{A-14}$$

and

$$k^4\sqrt{B_3}\left(\frac{\ell_3}{x}\right) = a_1 . \tag{A-15}$$

Position of sources

Since we have measured values of a_0 and a_1 for two positions along the diffuser we can use equations (A-13) to (A-15) to calculate the approximate position of each of the three sources. Let these positions be respectively x_1, x_2 and x_3 downstream of D_1 and let the distance between D_1 and D_2 be D .

Without the second throat the relevant equations are (2) and (3). From these equations for the monopole sources equation (A-13) gives

$$\frac{D - x_1}{x_1} = \frac{0.84}{1.54} \quad \text{or} \quad \underline{x_1 = 0.65D} . \tag{A-16}$$

For the dipole sources equation (A-14) gives

$$\frac{D - x_2}{x_2} = \sqrt{\frac{0.84 \times 1.24}{1.54 \times 0.73}} \quad \text{or} \quad \underline{x_2 = 0.51D} \; . \qquad \text{(A-17)}$$

For the quadrupole sources equation (A-15) gives

$$\frac{D - x_3}{x_3} = \frac{1.24}{0.73} \quad \text{or} \quad \underline{x_3 = 0.37D} \; . \qquad \text{(A-18)}$$

With the second throat the relevant equations are (4) and (5). From these equations for the monopole sources equation (A-13) gives

$$\frac{D - x_1}{x_1} = \frac{1.00}{1.70} \quad \text{or} \quad \underline{x_1 = 0.63D} \; . \qquad \text{(A-19)}$$

For the dipole sources equation (A-14) gives

$$\frac{D - x_2}{x_2} = \sqrt{\frac{1 \times 1.60}{1.7 \quad 1.60}} \quad \text{or} \quad \underline{x_2 = 0.57D} \; . \qquad \text{(A-20)}$$

For the quadrupole sources equation (A-15) gives

$$\frac{D - x_3}{x_3} = \frac{1.60}{1.60} \quad \text{or} \quad \underline{x_3 = 0.50D} \; . \qquad \text{(A-21)}$$

These positions are shown in Fig 13b: with the second throat the dipole and quadrupole noise sources are displaced further down the diffuser by the blocks added to the model support strut and the change to the sidewalls. This downstream displacement of these sources helps to explain why the second throat only createst a little additional noise in the working section before choking[1].

Estimation of diffuser velocity ratio from far field noise

It is reasonable to suggest that the effect of the second throat is only to alter the positions of the noise sources and to change the noise by changing the diffuser velocity ratio. Subject to these assumptions, B_1, B_2, B_3 and ℓ_1, ℓ_2 and ℓ_3 will all be unchanged by the second throat. Hence equations (A-13) to (A-15) can be used to derive the ratio of the inlet diffuser velocities

Ae 2201

$$\frac{U_d \text{ with second throat}}{U_d \text{ without second throat}} = \frac{k_1}{k} = \kappa \; . \qquad \text{(A-22)}$$

For the monopole noise, from equations (A-13), (A-16) and (A-19), (2) and (4)

$$(\kappa)^2 \frac{0.65D}{0.63D} = \frac{1.00}{0.84} \quad \text{or} \quad \kappa = 1.07 \; . \qquad \text{(A-23)}$$

For the dipole noise, from equations (A-14), (A-17), (A-20), (2) and (4):

$$(\kappa)^3 \frac{0.51D}{0.57D} = \sqrt{\frac{1.00}{0.84} \quad \frac{1.60}{1.24}} \quad \text{or} \quad \kappa = 1.12 \; . \qquad \text{(A-24)}$$

For the quadrupole noise, from equations (A-15), (A-18), (A-21), (2) and (4):

$$(\kappa)^4 \frac{0.37D}{0.50D} = \frac{1.60}{1.20} \quad \text{or} \quad \kappa = 1.15 \; . \qquad \text{(A-25)}$$

The average value for the diffuser velocity ratio given by equations (A-23) to (A-25) is

$$\kappa \approx 1.11 \; . \qquad \text{(A-26)}$$

For the same free-stream conditions the diffuser inlet velocity ratio will be inversely proportional to the geometric contraction ratio of the second throat, (0.89) from Ref 1, *ie*

$$\kappa = \frac{1}{0.89} = 1.12 \; . \qquad \text{(A-27)}$$

Equations (A-27) and (A-26) are in excellent agreement. This suggests that despite the many approximations made the simplified model for the diffuser noise suggested is adequate for engineering design.

It is interesting to observe that the best estimate of the diffuser velocity ratio from the noise measurements is derived from the dipole noise. This indicates the importance of this term, which is probably due to the fluctuating lift generated by the vortices from the vertical supports at the downstream end of the plenum chamber. These supports are unrepresentative of those that will be used in the full scale tunnel and hence these diffuser noise measurements may also be unrepresentative of the full-scale tunnel.

Despite this caveat, the success achieved by this simple model for the diffuser noise implies that if the flow is separated at ambient conditions it will be separated over the full range of Mach number and Reynolds number and total temperature. The reattachment region is probably in the vicinity of the dipole and quadrupole sources, *ie* about halfway down the diffuser.

LIST OF SYMBOLS

a	velocity of sound
B_1, B_2, B_3	source of strengths (equation (A-9))
D	distance between measurement points (equation (A-16))
f	frequency (Hz)
$k = \frac{U_d}{U}$ =	$\frac{\text{diffuser inlet velocity}}{\text{velocity in working section}}$ equation (A-1))
k_t, k	diffuser inlet velocity ratios with and without second throat (equation (A-22))
ℓ_1, ℓ_2, ℓ_3	characteristic lengths of mixing region
M	free stream Mach number
M_d	diffuser inlet Mach number (equation (A-2))
$\sqrt{nF(n)}$	flow unsteadiness (equation (1) and Ref 2)
$n = fw/U$	frequency parameter based on tunnel width
$\overline{(p)^2}$	mean square pressure fluctuation
$\bar{p}$	rms pressure fluctuations
T_t	tunnel total temperature (K)
$q = \frac{1}{2}\rho U^2$	kinetic pressure in working section
U	free stream velocity in working section
U_d	diffuser inlet velocity
w	tunnel width in working section
x	distance from source to measurement point (equation (A-3))
x_1, x_2, x_3	distance of effective monopole, dipole and quadrupole noise sources downstream of D_1 (equations (A-18) to (A-21))
$k = \frac{k_t}{k}$	ratio of diffuser velocities with and without second throat (equation (A-22))
ρ	free stream density (equation (A-3))

Ae 2201

REFERENCES

No.	Author	Title, etc
1	D.G. Mabey	Noise measurements in a slotted cryogenic wind tunnel. RAE Technical Report (to be issued)
2	T.B. Owen	Techniques of pressure fluctuation measurements employed in the RAE low-speed wind tunnels. AGARD Report 172 (1958)
3	D.G. Mabey	Flow unsteadiness and model variation in wind tunnels at subsonic and transonic speeds. CP 1155 (1971)
4	D.G. Mabey	Some remarks on the design of transonic tunnels with low levels of flow unsteadiness. NASA CR 2722 (1972)
5	M.J. Lighthill	Jet Noise. *AIAA Journal*, 1, 7, pp 1507-1517 (1963)
6	D.G. Mabey	A semi-empirical theory for the noise level in slotted tunnels with diffuser suction. RAE Technical Report (to be issued)

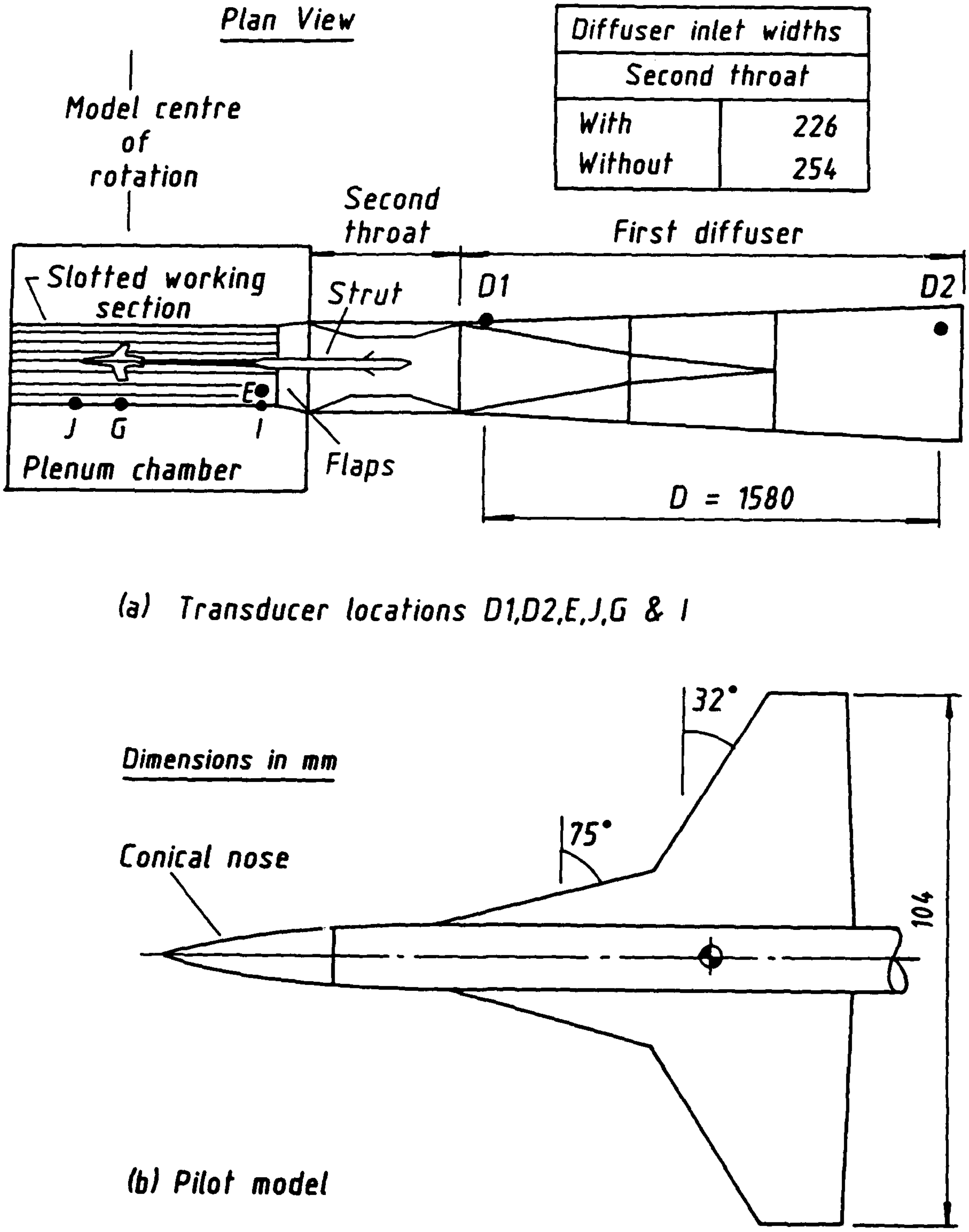


Fig 1 Instrumentation and model for diffuser noise tests

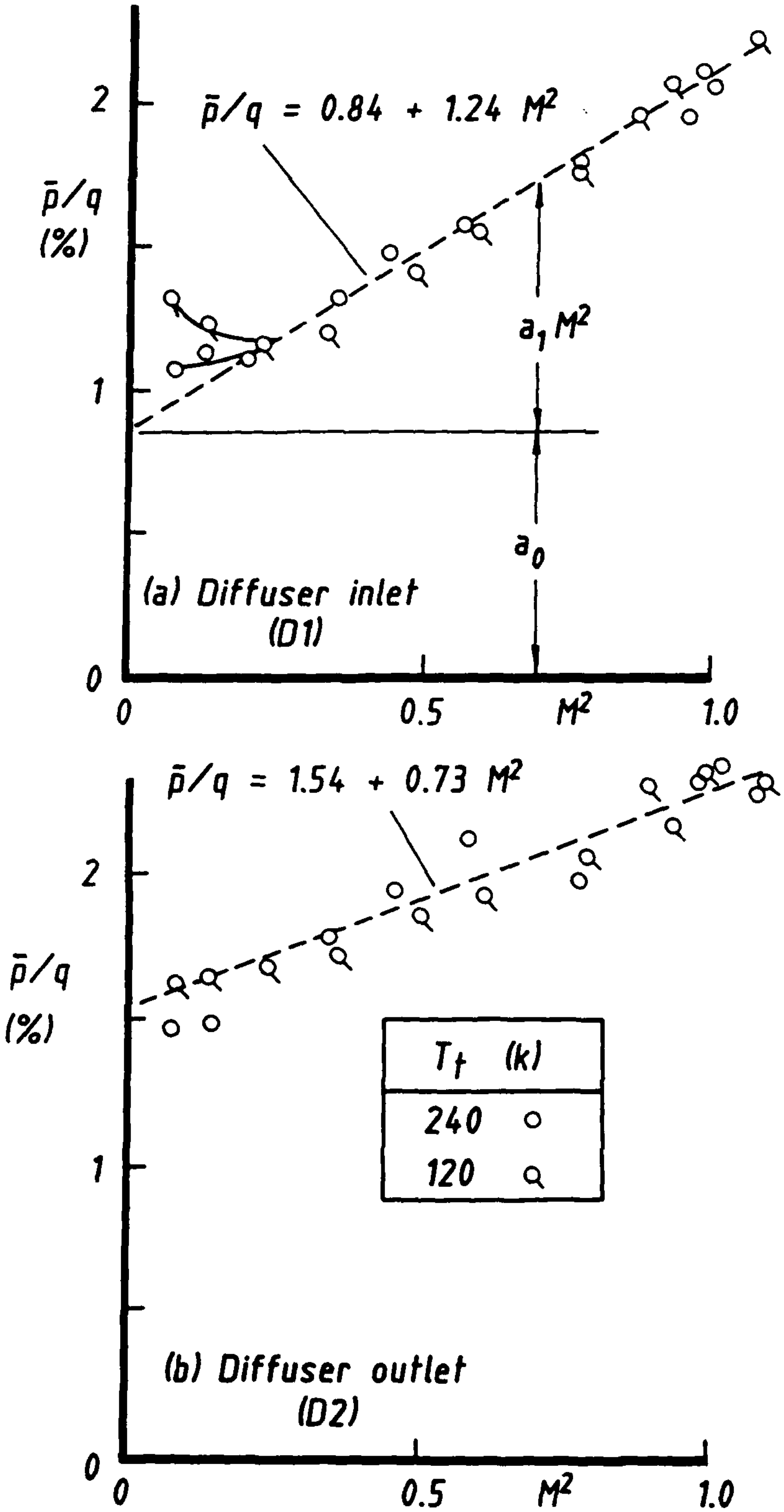


Fig 2 Without second throat: variation of rms noise with (Mach number)^2

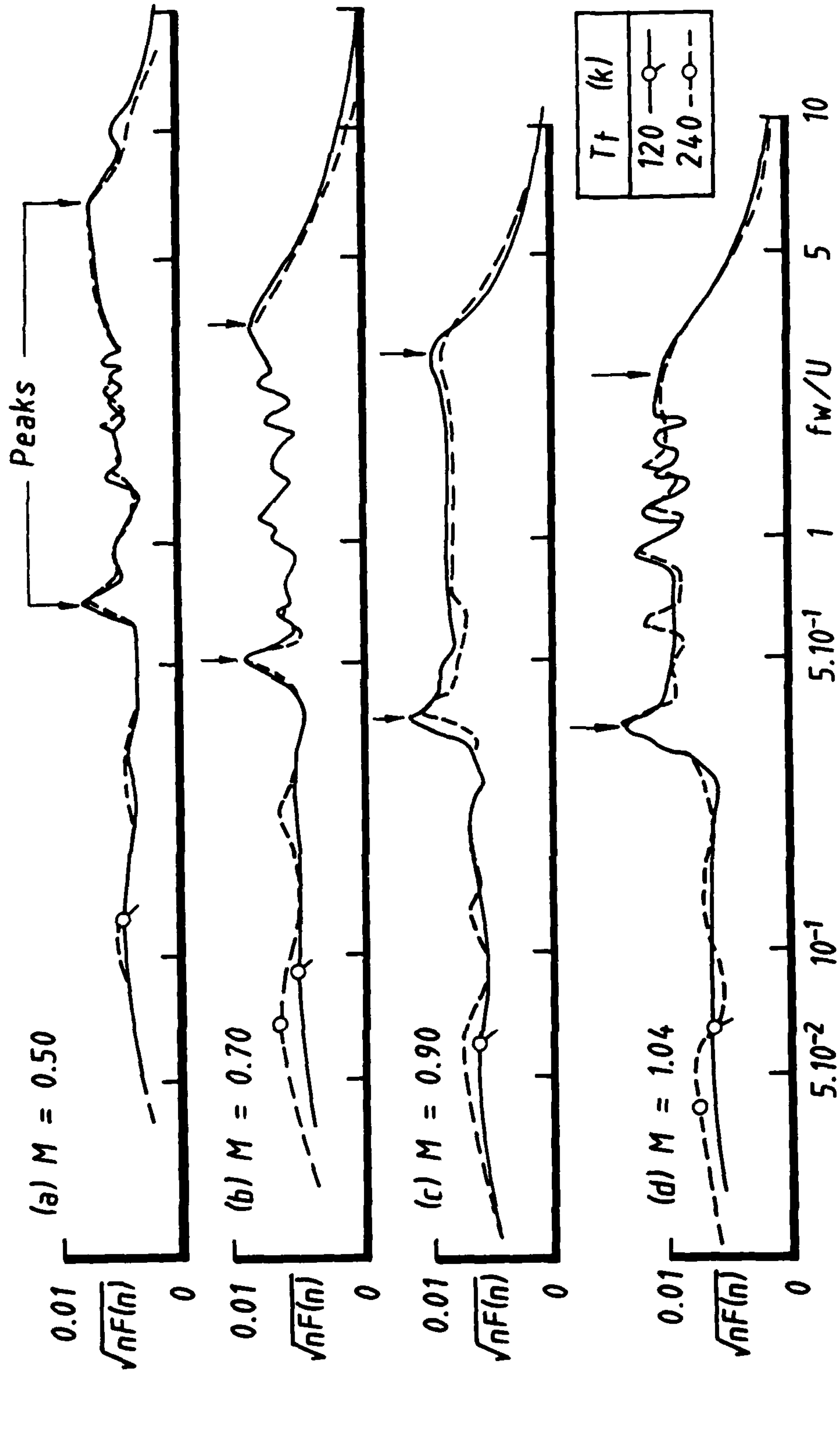


Fig 3 Without second throat: pressure fluctuation spectra at diffuser inlet

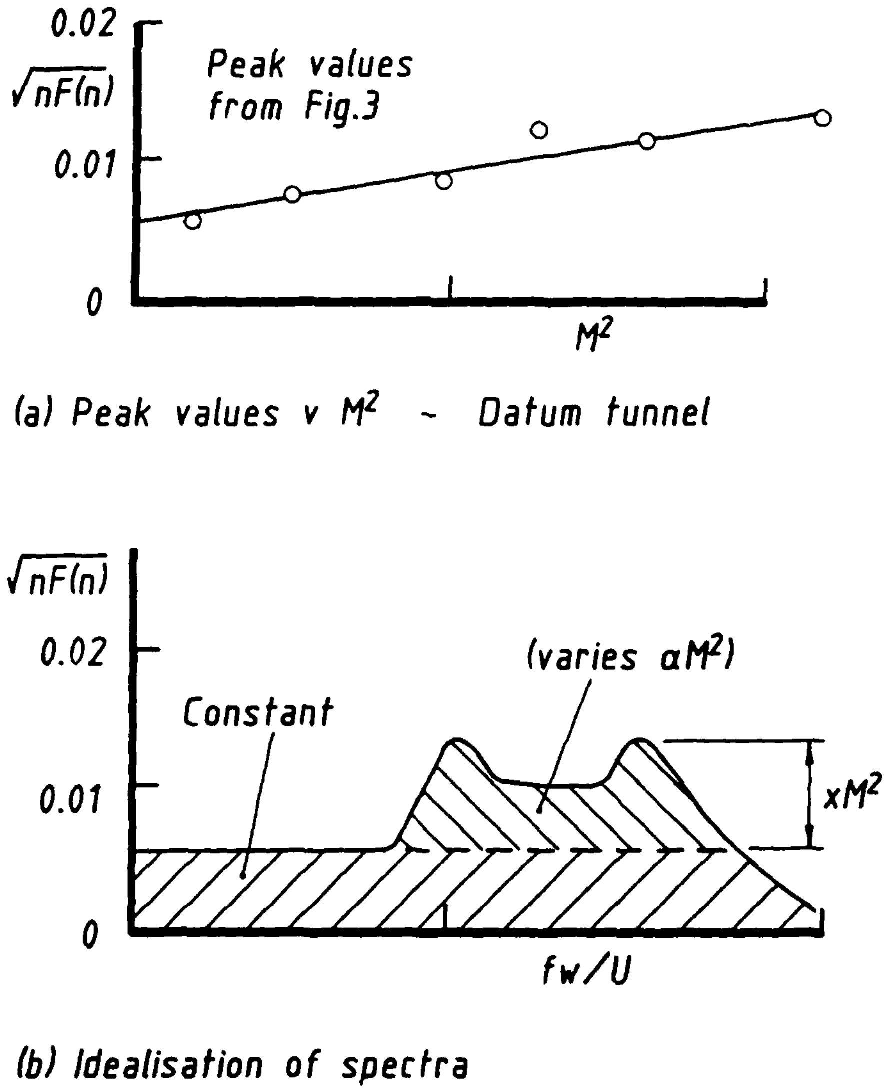


Fig 4 Synopsis of diffuser inlet spectra

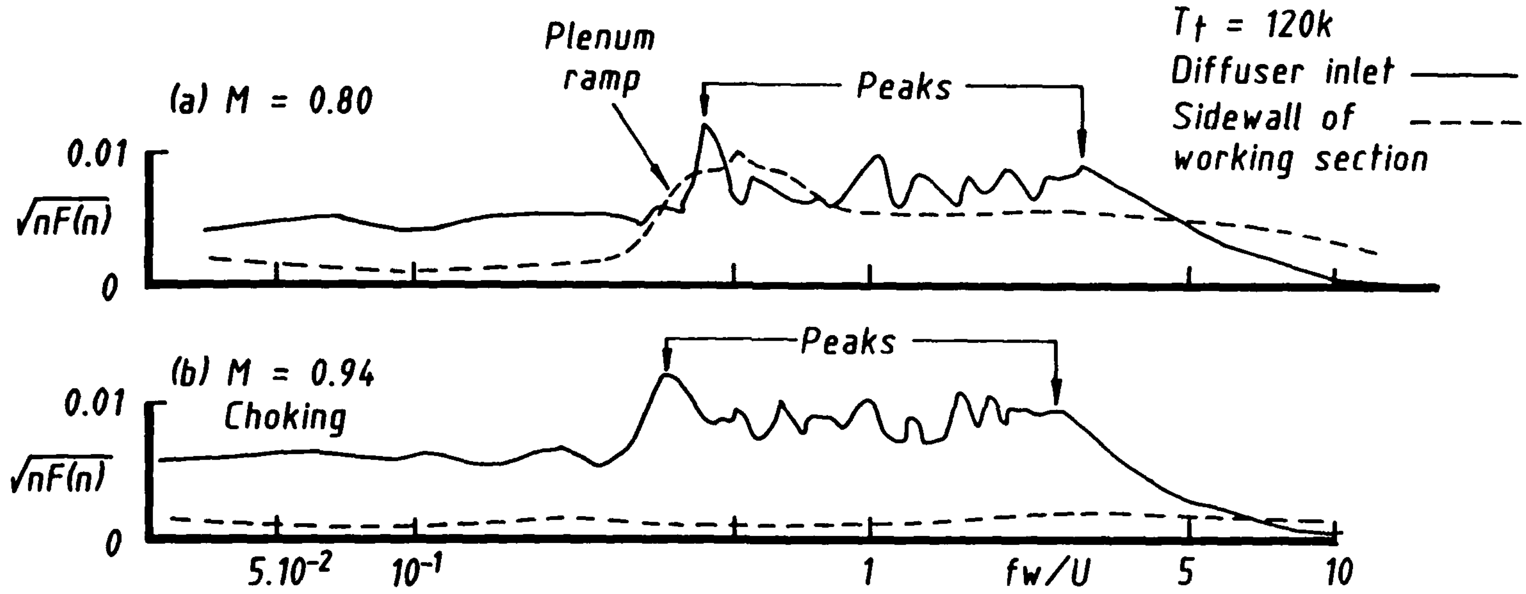


Fig 5 Without second throat: comparison between sidewall and diffuser entry noise spectra

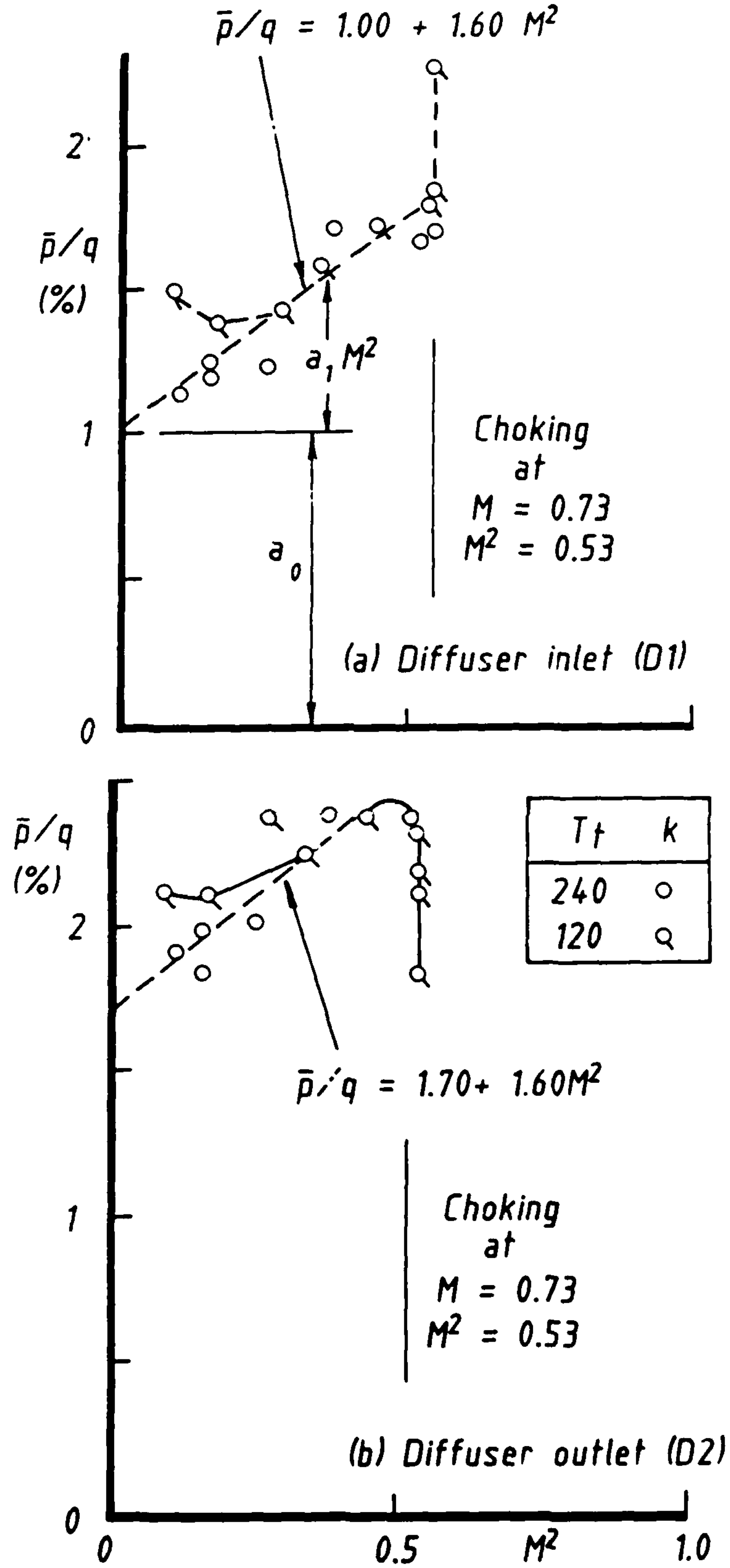


Fig 6 With second throat: variation of rms noise with (Mach number)^2

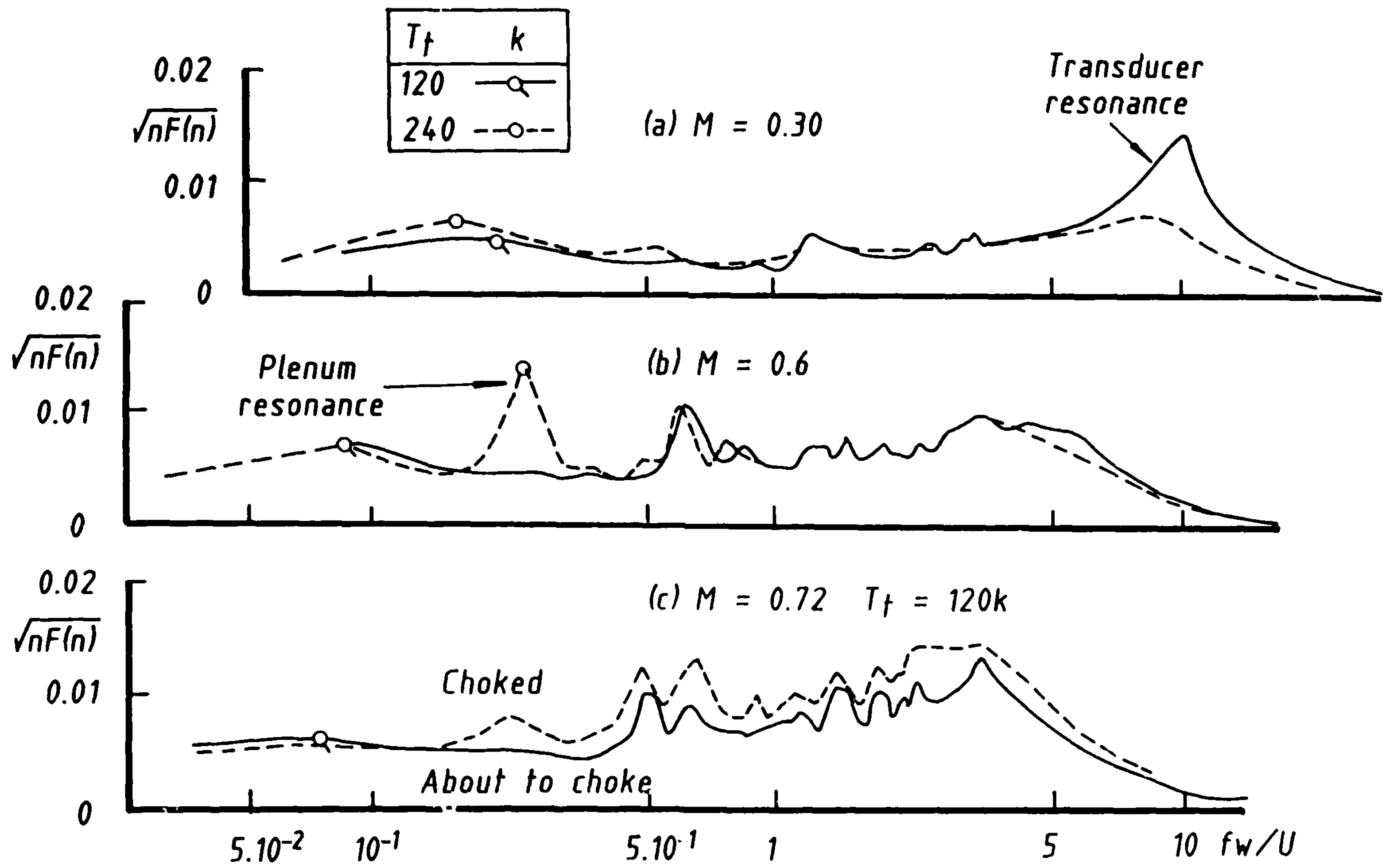


Fig 7 With second throat: typical noise spectra at diffuser inlet

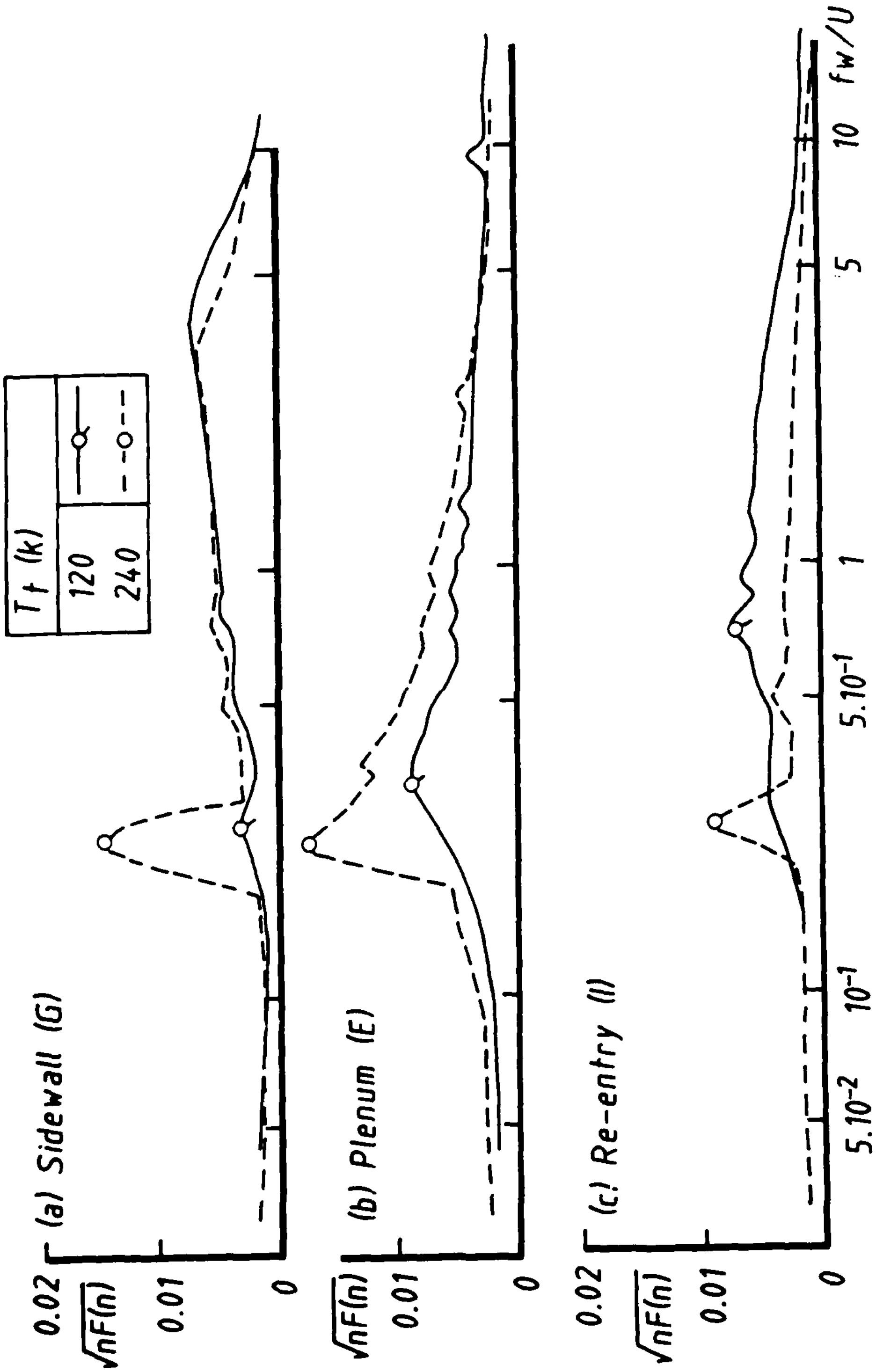
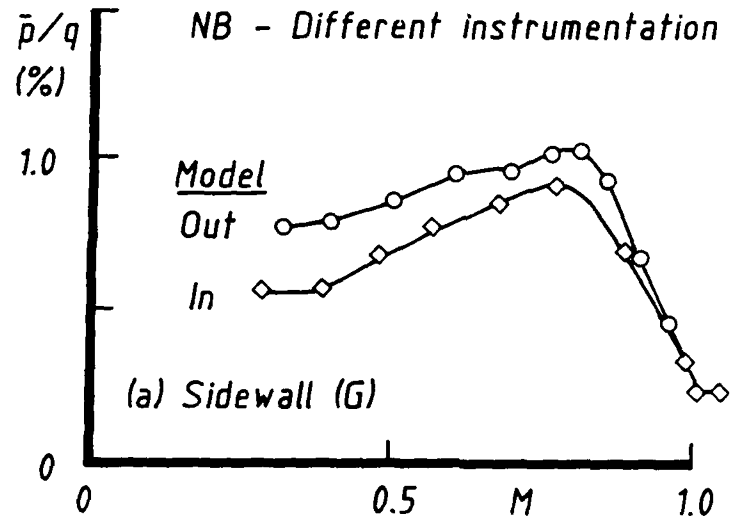


Fig 8 With second throat: noise spectra at sidewall, plenum and re-entry at M = 0.6



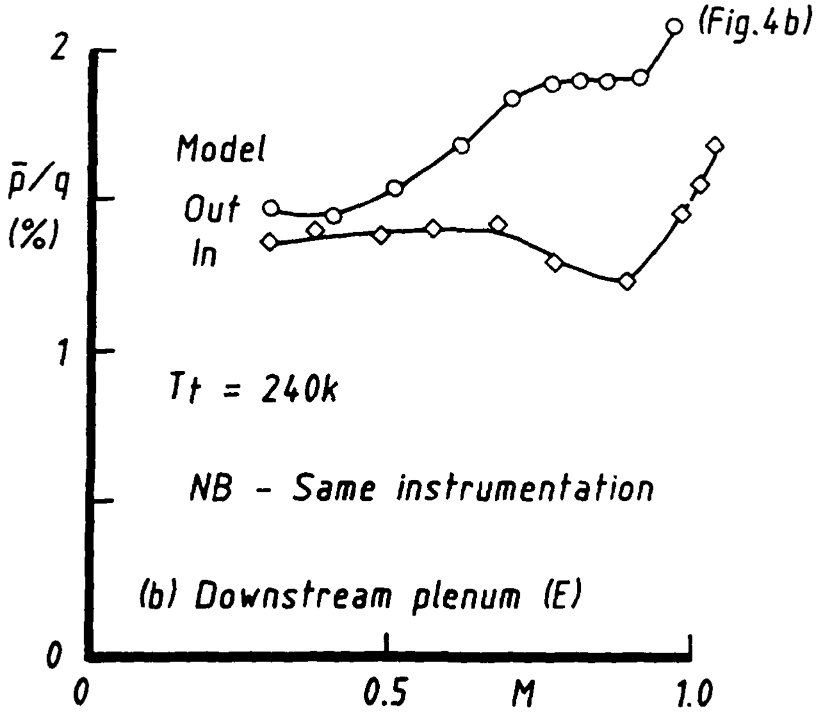


Fig 9 **Without second throat: variation of rms noise with Mach number showing influence of model**

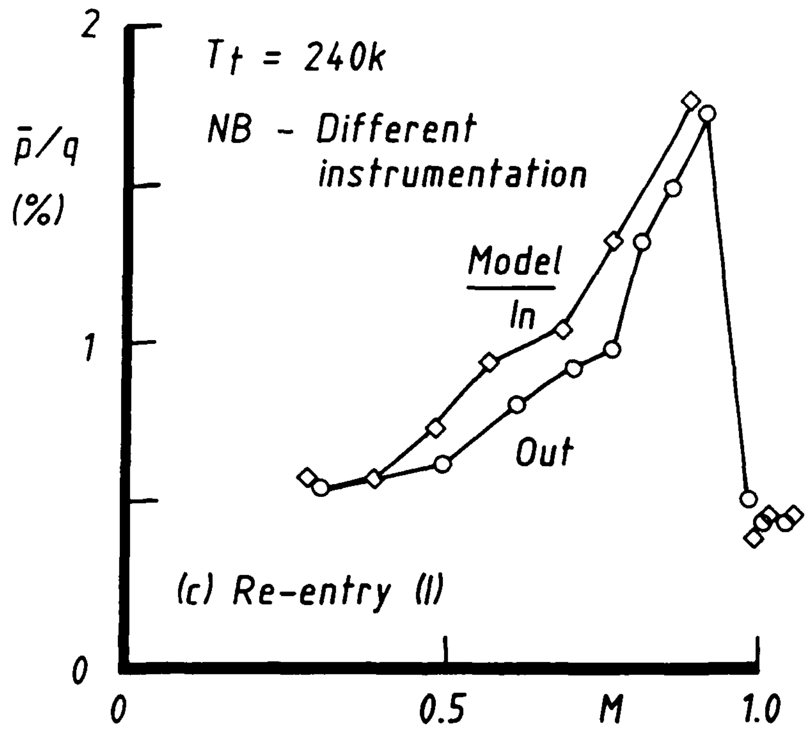


Fig 9 (concluded)

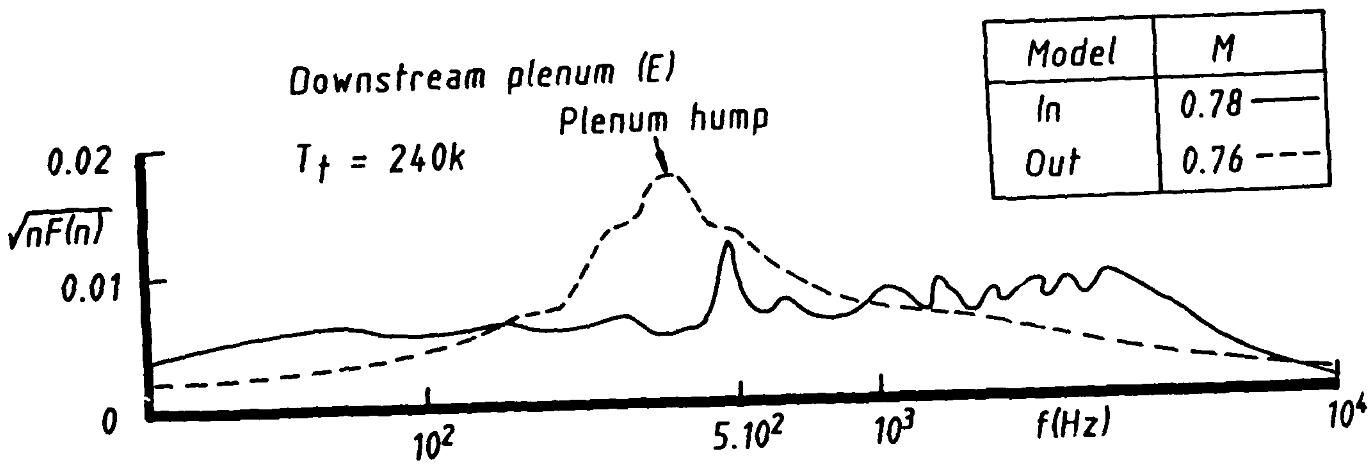


Fig 10 Without second throat: spectra of noise in plenum chamber near M = 0.8 showing influence of model

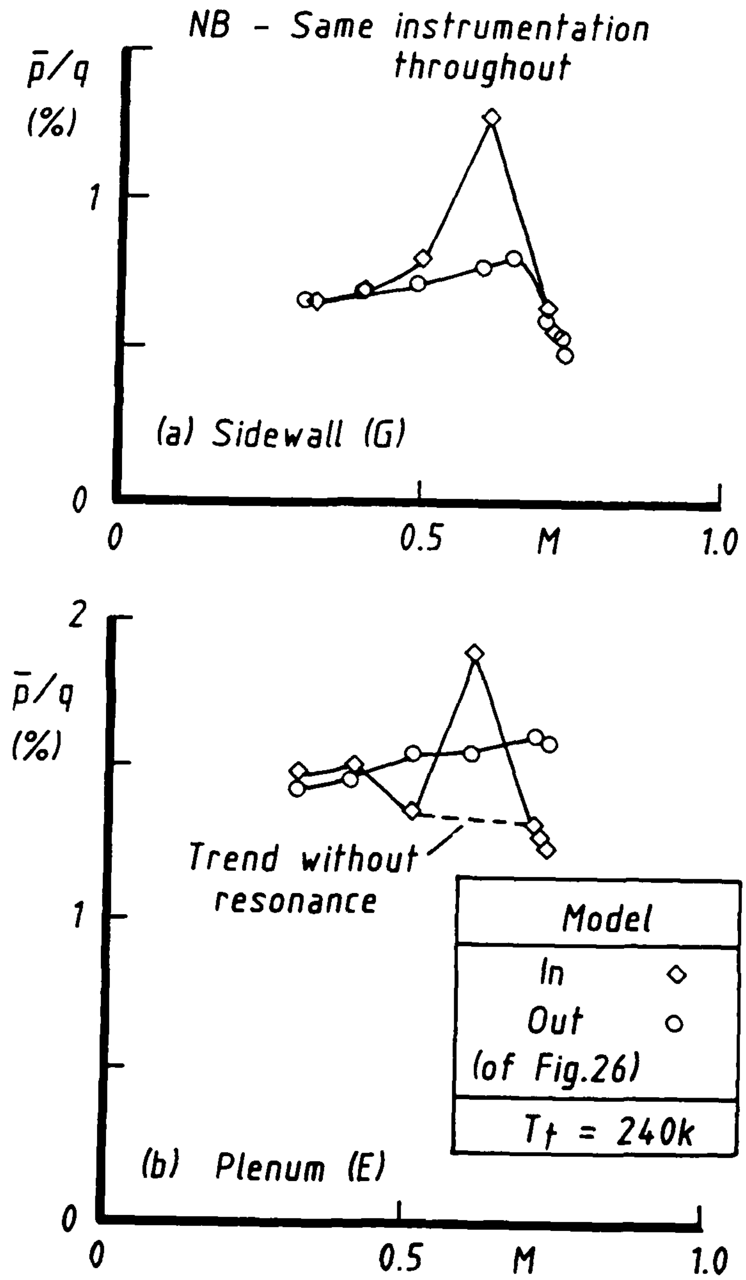


Fig 11 With second throat: variation of rms noise with Mach number showing influence of model

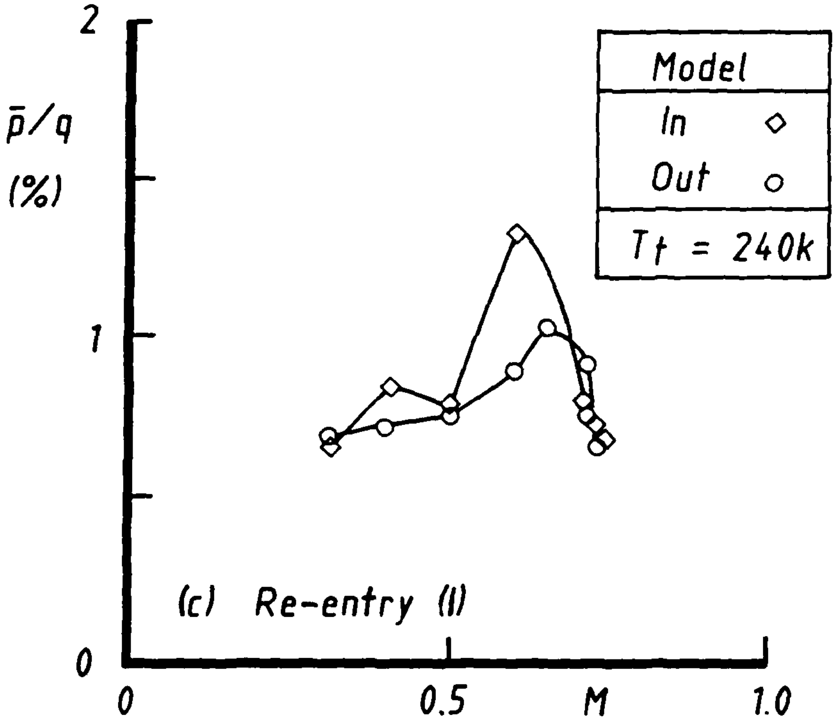


Fig 11 (concluded)

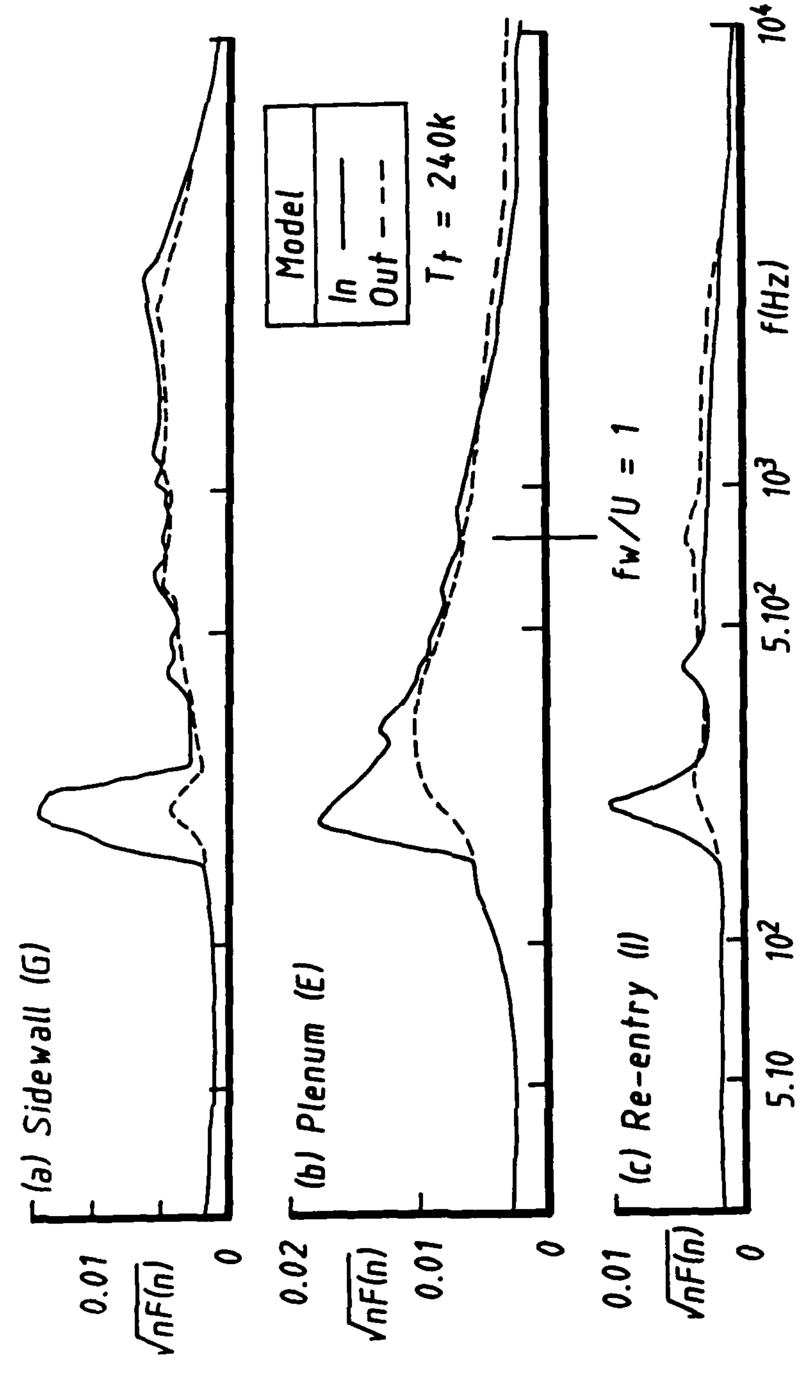
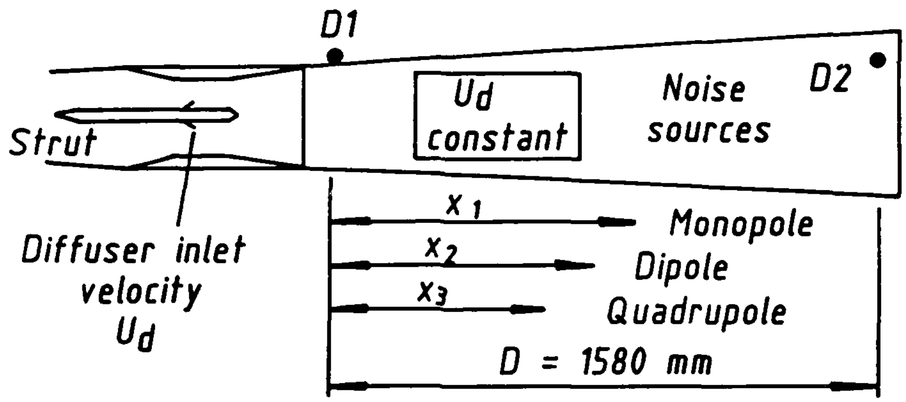


Fig 12 With second throat: comparison of spectra at M = 0.6 showing large influence of model



(a) Idealisation of diffuser noise sources

Type of source	Position along diffuser x/D		Velocity ratio k
	Without second throat	With second throat	
Monopole	0.65	0.63	1.07
Dipole	0.51	0.57	1.12
Quadrupole	0.37	0.50	1.15
Physical flow	? Separated ?		1.12 (geometric)

(b) Inferred noise sources

Fig 13 Approximate model for diffuser noise

REPORT DOCUMENTATION PAGE

Overall security classification of this page

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15. Distribution statement

(a) Controlled by – Head of Aero Dept

(b) Special limitations (if any) –

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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

Unsteady aerodynamics.

17. Abstract

This Memorandum describes some noise measurements in a cryogenic wind tunnel with slotted walls at subsonic and transonic speeds. Pressure fluctuations were measured at three positions on the sidewall of the working section, the downstream end of the plenum chamber and near the inlet and outlet of the first diffuser.

Analysis of the measurements suggests that the diffuser noise field can be represented by the superposition of monopole, dipole and quadrupole sources. The existence of these sources suggests that the diffuser flow may be separated for a significant portion of its length, either because of poor entry conditions or the presence of the model support strut. As expected, a small model at a small angle of incidence generally has a small effect on the noise measurements in the working section. Recommendations are made for further research.

F5910/1

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